High-Resolution Monitoring at Parkfield
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Program Element II

Key Words:
Source characteristics
Fault dynamics
Fault stress interactions
Earthquake forecasting

Investigations Undertaken

The year's research addressed three scientific questions: 1. Variations in recurrence rates of characteristic sequences and implications for a changing fault slip rate, 2. Source parameter scaling to M<0 events and implications for conditions at the hypocenter, 3. Numerical modeling of the observed travel-time changes in the Vibroseis monitoring project.

In addition, funds were obtained to upgrade the network hardware that had failed in late 1998, shutting down the data acquisition just as Parkfield had become the site of the international fault zone drilling initiative (SAFOD). The process of equipment purchase and site preparation began in earnest in mid-1999 and is ongoing.

Results

Unique attributes in sequences of recurring, similar microearthquakes at Parkfield `provide a means for inferring slip rate at depth throughout the active fault surface from the time intervals between sequence events. Application of the method using an 11-year microseismicity record revealed systematic spatial and temporal changes in the slip rate that were synchronous with earthquake activity and other independent measures of fault-zone slip. If this phenomenon is found to be generally common behavior in active faults, it forms the basis for a method to monitor the changing strain field throughout the seismogenic fault zone. Initial extension of the method to adjacent segments of the SAF show similar characteristic transients in inferred fault slip rate, and we are extending the study to the complete San Andreas system in central California.

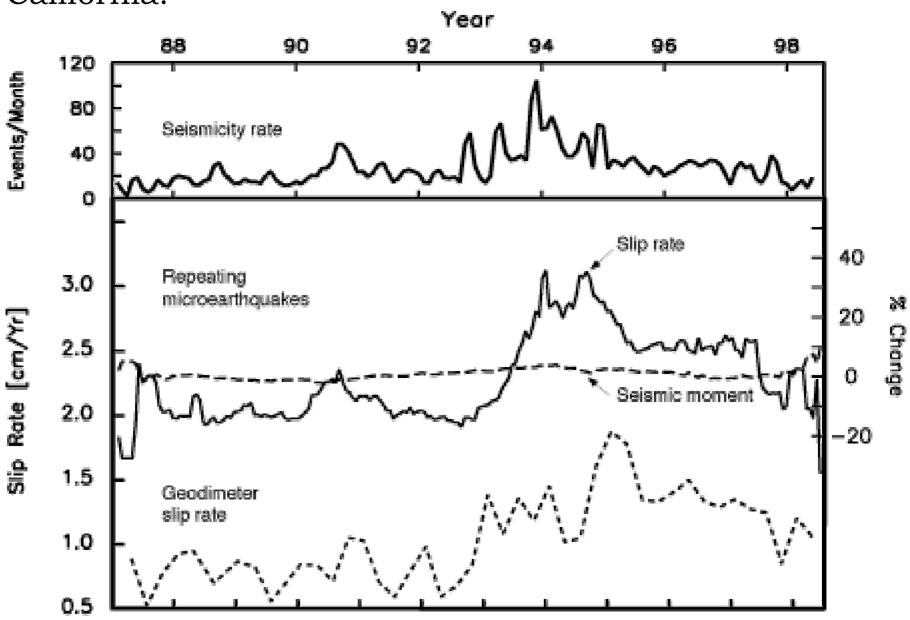

Figure 1. Top. Seismicity rate smoothed with a 2-month running window. Center. Variations in recurrence-derived slip rate (solid) and sequence-normalized seismic moment (dashed) for the 160 sequences studied. Left scale is absolute slip rate, right scale is relative change in slip rate and moment. Bottom, Slip-rate from the 2-color laser geodimeter at the location shown in Fig. 3.

Observations of repeating earthquake sequences on the central SAF ranging in size from magnitude -1 to 6 show that recurrence intervals increase more slowly with event size and are disproportionately longer for increasingly smaller events than predicted by models of constant fault strength. At the same time, studies of the spatial and temporal distribution of slip rates using recurrence intervals show that slip rates at depth are in good agreement with slip rate distributions on Earth's surface when an average regional rate of 2.3 cm/yr. is assumed. This supports the argument that fault slip rates at depth are comparable to geodetic rates at the surface. Under such conditions, the longer recurrence intervals for smaller earthquakes indicate a proportionately greater contribution of seismic slip to seismic moment and a complementary reduction in the contribution of rupture area to moment. Consequently, the ratio of seismic slip to rupture dimension -- a measure of both slip localization and fault strength -- should increase with decreasing magnitude. Additional evidence that rupture area for smaller earthquakes is disproportionately small is found from results of high-precision relative location analyses of microearthquakes at Parkfield which show discrete co-planar sites of repeating earthquakes separated by distances less than their predicted source dimensions. The results also show temporal interactions between the proximal sites to be indicative of distinctly non-overlapping rupture, supporting the spatial results. Evidence of small rupture dimensions should also be observable as unusually high source corner frequencies in the spectra of seismograms.

Spectral ratio analyses between similar co-planar earthquakes at Parkfield having identical mechanisms, separated by very small distances (approx. ~< .020 km) and having significantly different magnitudes provide resolution of very subtle differences in source characteristics, in particular source corner frequencies, without the need for invoking heavily model dependent attenuation, path, and radiation pattern corrections. Current theory predicts that ratios between events with magnitude differences of 1 will have source corner frequencies that differ by about a factor of 3. Preliminary analyses for events of magnitude 1 and less show ratios to be flat out to at least 80 Hz and to exhibit an unstable pattern at higher frequencies, in contrast to the 2 or 3 slope moveout predicted by theory. This suggests that above ~80 Hz the data may lose measurable coherence, possibly due to near source scattering, and that source corner frequencies of events of magnitude ~1 are at least 80 Hz while those for the smaller events are substantially higher.

Pseudotachylites have long been associated with seismic activity, and it is generally accepted that failure due to high stresses causes cataclasis and partial melting. From the geometry of veins and their composition the energy required for melting can be calculated. For a statistical study of pseudotachylite geometry the large zone in the Eastern Peninsular Ranges in Southern California was investigated. Pseudotachylites are of granodioritic composition and have been dated at 55-60 My. Microstructures with spherulitic microlites of plagioclase, biotite and ilmenite are indicative of partial melting of up to 50% of the rock at temperatures exceeding 1000 C. There is a wide range of sizes from 0.2-10cm in thickness and 2-500cm in length with log-normal distributions. The energies for melting such material ranges from 105 J for smaller veins to 1010 J for larger ones. Making some assumptions about seismic efficiencies, seismic moments for pseudotachylite veins can be calculated. Each vein corresponds to a microseismic event and suggests that seismicity occurs in small local spots due to stress localization. The distribution of moment versus area in ancient pseudotachylites shows a pattern that is surprisingly similar to that observed completely independently for microseismicity along the San Andreas fault near Parkfield, suggesting that mechanisms for the two features may be similar.

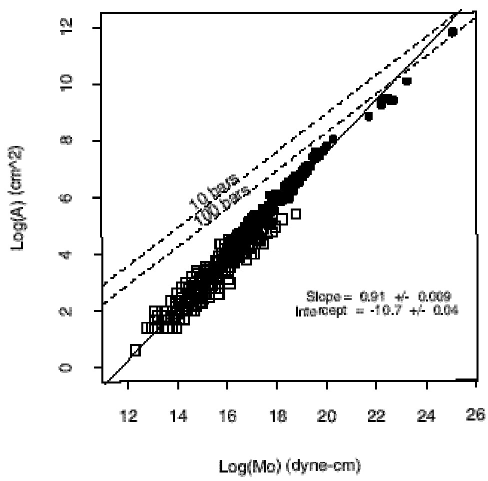

Figure 2. Source scaling (area vs. moment) for combined earthquake and psuedotachylite data, spanning 14 orders of magnitude in a linear relationship.

For ten years, as one element of this project, the borehole seismographic network there was illuminated routinely by a large shear-wave Vibroseis from several source points to investigate the stability of wave propagation in the fault zone and the possibility of nucleation-related premonitory phenomena. Clear and progressive travel-time changes of up to 50 msec were detected during the study, most prominent in the S-wave coda, and localized to propagation paths through the shallow fault zone (above about 500m depth) southeast of Middle Mountain, the section of the fault where previous M6 earthquakes have initiated. We model the observations successfully as interaction (reflection and transmission) of the shallow wavefield with a 200-meter-wide low-velocity fault zone in which the velocity increases by 6%, due, we hypothesize, to hydrological changes accompanying a significant pulse in fault slip rate and seismicity.

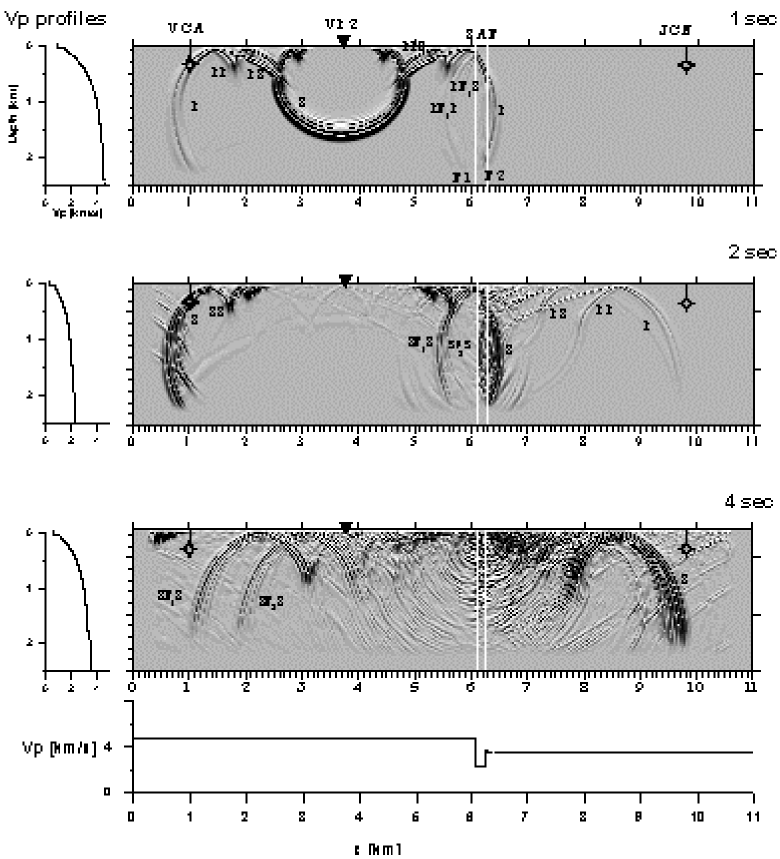

Figure 3. Finite difference modeling of wave propagation in the vicinity of the San Andreas fault, showing he interaction of the wave field with the low-velocity fault zone. The observed travel-time changes from VP2 to stations VCA and JCN can be explained with a 6% velocity increase in the shallow fault zone.

Non-technical Summary

Intensive monitoring at the Parkfield Earthquake Prediction Experiment site in central California, under the direction of Thomas V. McEvilly of the University of California, Berkeley. This research involves the operation and maintenance of the high-sensitivity network of seismographs in the area, the use of a large, truck-mounted vibrator to generate seismic waves to probe the subsurface along the fault zone on a regular schedule, and the analysis and archiving of the data acquired. The goal of the study is to detect anomalous precursors in microearthquake activity or in wave propagation to the expected magnitude 6 earthquake .

Reports Published

Articles:
McEvilly, T.V. and E. Karageorgi, Enhanced observations with borehole seismographic net510 642-4494 works: The Parkfield, California experiment, in *Proceedings*510 643-5811 (FAX) *of the 1st Workshop on the Development of a Multibore hole Observatory at the Gulf of Corinth*, ICDP Report, 1996/97, 1998.
Nadeau, R. M. and L. R. Johnson, Seismological Studies at Parkfield VI: Moment Release Rates and Estimates of Source Parameters for Small Repeating Earthquakes, Bull. Seism. Soc. Am., **88**, 790-814, 1998.
Nadeau, R.M. and T.V. McEvilly, Fault slip rates at depth from recurrence intervals of repeating microearthquakes, Science, **285**, 718-721, 1999.
Korneev, V.A., T.V. McEvilly and E.D. Karageorgi, Seismological Studies at Parkfield VIII: Modeling the Observed Controlled-Source Waveform Changes, Bull. Seism. Soc. Am., **90**, (in press), 2000.

Presentations (abstracts):
Geological Society of America Cordilleran Section Centennial 1899-1999, Berkeley, CA, 2-4 June, 1999.
T. V. McEvilly and R.M. Nadeau, Deformation Process In A Seismogenic Fault Zone From High-Resolution Studies Of Microearthquake Occurrence (Invited).
Plate-Boundary Observatory Workshop, Snowbird, UT, 03-05 October, 1999
T. V. McEvilly, Investigation Of Plate-Boundary Deformation Using High-Resolution Studies Of Microearthquake Occurrence (Invited).
1999 Fall AGU, San Francisco, 13-17 Dec.
R.M. Nadeau, L.R. Johnson, H. Wenk and T.V. McEvilly**,** Source Dimensions of Small Earthquakes.
H. Wenk, L.R. Johnson, R.M. Nadeau and T.V. McEvilly, A Statistical Investigation of Pseudotachylites in Southern California.
R. M. Nadeau and T.V. McEvilly, Cluster Signature Analysis of Earthquakes on Central San Andreas and Bay Area Faults.

Data Availability

All of the data are archived on the Northern California Earthquake Data Center in Berkeley (www.seismo.berkeley.edu) in MiniSEED format.